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Contribution to emission reduction of CO_2 and SO_2 by household biogas construction in rural China

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Abstract

Rural household biogas construction is a key program of renewable energy construction in China, which can partly help to reduce the problem of global warming.

This article uses the international commonly used calculation of emission reduction to analyze the quantity of reduction in CO_2 and SO_2 emissions, which is resulting from the substitution of household biogas in place of traditional biomass energy and coal during the period from 1996 to 2003. The result shows that such substitution can reduce the discharge of CO_2 by 397.6–4193.9 thousand tons and SO_2 by 21.3–62.0 thousand tons annually. This article then predicts the amount of reduction in CO_2 and SO_2 emissions that would occur in 2010, 2020 and 2050 with the substitution of biogas energy instead of traditional energy sources in rural areas. All of these prove that rural biogas construction is an effective means of reducing the emission of greenhouse and other harmful gases into the atmosphere.

Keywords: Rural household biogas; CO_2 emission reduction; SO_2 emission reduction

Contents

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1. Introduction

The increase of greenhouse gases in the atmosphere mainly stems from human activities. In the past 20 years, 75% of CO_2 discharged into the atmosphere in the world was caused by the burning of fossil fuels, with an annual average growth rate of 0.4% [1]. In recent years, the annual emission of CO_2 by China has accounted for more than 13% of the global total [2]. At the same time, the energy consumption of coal has also kept the growth rate of SO_2 emissions to over 10%. Both of these make China a major contributor to the international energy and environmental problem. In China, development of the rural economy and improvement of rural living standards depend on sufficient energy supplies. In addition, the consumption of commodity energy is very low, and non-commodity energy accounts for the majority of household energy consumption in rural areas. Among the non-commodity energy, locally obtainable biomass energy, whose burning causes a great deal of CO_2 emission, takes the lion's share and accounts for more than 15% [2] of the rural energy consumption. For this reason, China is making great efforts to strengthen the development and construction of renewable energy in order to alleviate the imbalance between energy demand and supply, as well as to ease the environmental pollution. However, research in this field is still in the early stages and relevant studies are few at present.

Biogas technology processes the waste products from daily life making anaerobic ferment which in turn produces biogas, with its main component, methane. Methane is convenient to use, is clean and produces no pollution. The remains of the ferment can be used in agricultural production as good feed and fertilizer and, where the materials are sufficient and conditions are suitable, sustained production can be achieved. With its characteristic of generating high heat, biogas can be used as a substitute for straw, firewood and coal as daily fuel. This can not only reduce the discharge of such noxious gas as CO_2, SO_2 and so on, thus purifying the air [3], but also lower the incidence of respiratory track diseases. Therefore, the biogas construction project is an effective measure to solve the rural energy supply problem, and is also helpful to reduce the emission of greenhouse and harmful gases [3] in the rural areas.

2. Energy consumption for livelihood in rural China and the development of household biogas

2.1. The current situation of energy consumption for livelihood in rural areas

The energy for rural family livelihood is closely related to the local kinds of fuel sources, the obtainable amount, the economic development and the commodity energy supply.

In China, rural household energy consumption accounts for about 16.7% of the country's disposable energy consumption. Since it is difficult to obtain commodity energy in the vast rural areas, more than 66.7% of rural residents' energy for daily life depends on traditional biomass energy [4], thus leading to an excessive consumption of biomass energy and causing serious soil erosion, ecological environmental disruption and the decrease of organic substances in the soil. Table 1 shows the situation of rural China's energy consumption for livelihood in recent years.

China is one of the few countries in the world still using coal as its main energy source. The quantity of coal consumption accounts for more than 70% [4] of the total amount of energy consumed. Industrial and agricultural production uses the majority, while consumption for livelihood is less and is mainly in the rural areas. As rural residents' income increases and their living standard improve, the demand for commodity energy is becoming increasingly urgent. This means that the proportion of coal being used in rural energy consumption for livelihood is rising, resulting in, not only a great amount of CO_2 being discharged, but is also producing SO_2 and other noxious gases that threaten human health. The amounts of coal consumption for livelihood in the rural areas in 1996 and 2002 were 141,442.9 thousand tons and 220,383.2 thousand tons, respectively. This is equivalent to 100,990.2 thousand tons and 157,350.0 thousand tons of standard coal, indicating an annual increasing rate of 7.67%. There was also an increased proportion of coal used in relation to the total energy consumption for livelihood rising from 29.64% to 34.70%. However, coal consumption in 2003 decreased by 2.7% [3] because of the improved efficiency of energy utilization and the wide use of new sources of energy. Except the emission of CO_2, at the same time SO_2 is also produced accompanying the burning of the coal. SO_2 is the main factor attributing to acid rain and is also the main pollutant in the atmosphere in China. Acid rain has affected about 30% of the country in recent years, and this area appears to be extending. Experts estimate that the direct economic loss caused by acid rain all over the country are about 1–2% of GDP every year, and that the potential loss may reach over 4% every year [3].

2.2. Construction of rural household biogas and its relationship with the surrounding environment

Since the 1990s, household biogas construction has developed rapidly in rural China because there are sufficient materials for ferment and decentralized energy consumption in these areas. This contributes to the sustainable development of energy, ecology and economy in the rural areas. In 1996, there were 4891.2 thousand households in the rural area all over the country using biogas. By 2003, after seven years' expansion, the number had increased to 12,286.0 thousand households with an annual increasing rate of 14.06%. The annual output biogas in 1996 and 2003 were 1,586,440.0 thousand cubic meters and 4,605,902.7 thousand cubic meters, respectively, equivalent to 1,132.0 thousand tons and 3,302.1 [3] thousand tons of standard coal. By 2003, the annual average output per household had reached 400 m^3 and the proportion of biogas consumption in rural energy consumption had risen from 0.33% to 0.72%.

Under normal conditions, the thermal efficiency of burning biogas can achieve 50% and a biogas pool of 8 m^3 can provide more than 80% of a household's daily energy requirements. Thus, it can save more than 2000 kg of firewood, thus protecting a forest of 2331 m^2 and reducing soil erosion by 3.2 tons [7]. The appearance of the methane kitchen

Table 1
Situation of rural energy consumption for livelihood from 1996 to 2003 /10^4 ton of standard coal

Years	Total energy for livelihood	Straw	Firewood	Coal	Electric power	Refined oil	Biogas (10^4 m^3)	LPG	Natural gas	Coal gas	Solar energy (10^4 m^3)
1996	34,069.49	11,996	8298	10,099	2914	471	113.20	153	9.71	14.61	1736
1997	–	12,139	8350	–	–	–	126.95	–	–	–	–
1998	36,583.61	11,488	10,018	11,223	2649	626	92.08	456	19.63	10.60	5231
1999	35,346.82	12,502	7790	10,998	2730	776	143.07	384	10.19	10.89	1271
2000	36,999.19	12,360	8051	11,800	3444	757	162.29	397	17.06	9.64	5605
2001	41,427.37	13,080	9757	13,778	2864	1304	220.00	388	23.41	11.67	1644
2002	45,347.08	14,147	11,401	15,735	2476	848	267.69	437	25.33	8.10	2433
2003	46,126.53	14,284	11,634	15,304	3001	1008	330.21	534	20.33	9.96	3861

Notes: (1) Calculated according to China Rural Energy Statistic [3] and Rural Energy Yearbook [5,6]; (2) Vacant of some datum of 1997.

Table 2
The proportion of energy consumption for rural livelihood from 1996 to 2003 /%

Years	1996	1998	1999	2000	2001	2002	2003
Straw	35.21	31.40	35.37	33.40	31.58	31.20	30.97
Firewood	24.36	27.39	26.37	21.76	23.55	25.14	25.22
Coal	29.64	30.68	31.12	31.90	33.26	34.70	33.18
Biogas	0.33	0.25	0.40	0.44	0.53	0.59	0.72

Notes: (1) Calculated according to China Rural Energy Statistic [3], 1996–2003; (2) Vacant of some datum of 1997.

stove has changed the rural woman's bad cooking condition, while methane lights provide daily illumination. Some researches [8] indicate that the indoor densities of CO, SO_2, CO_2 and TSP in a household burning coal are 73.94%, 83.80%, 27.00% and 77.00%, respectively, higher than those in a household burning biogas. Table 2 shows the proportion of energy consumption for rural livelihood.

3. Contribution to the reduction of CO_2 and SO_2 emission by household biogas construction in rural China

3.1. Calculation of CO_2 and SO_2 emissions

The burning of straw, firewood and coal is the main source of CO_2 and SO_2 emissions in the rural areas. This article calculates the benefit of rural household biogas construction in China to reduce such emissions based on the calculating method of Wang Gehua and others [9], namely the difference between emissions from biogas burning and emissions from the burning of the straw, firewood or coal.

The method of calculating CO_2 and SO_2 emissions from coal is as following:

$$C_c = 0.0209\ (\text{heat value, TJ/t}) \times 24.26\ (\text{emission coefficient of carbon, t/TJ}) \times 0.8\ (\text{oxidation rate of carbon}) \times 44/12 \times C = 1.487C. \quad (1)$$

In the formula, C_c is the quantity of CO_2 emission from civil coal (ton) and C is the consumption of civil coal (ton).

$$S_c = 16\ (\text{emission coefficient of } SO_2) \times 0.84\ \ (\text{average sulfur content}) \times C = 13.4C. \quad (2)$$

In the formula, S_C (kg) is the emission quantity of SO_2 by civil coal and C (ton) is the consumption of civil coal.

The quantity of CO_2 emission from biomass fuels is as following

For firewood,

$$C_W = W \times 0.45\ (\text{coefficient of carbon contained}) \times 0.87\ (\text{oxidation rate of carbon}) \times 44/12 = 1.436W. \quad (3)$$

For straw,

$$C_S = S \times 0.40\ (\text{coefficient of carbon contained}) \times 0.85\ (\text{oxidation rate of carbon}) \times 44/12 = 1.247S. \quad (4)$$

In the formulas, C_W (ton) and C_S (ton) are the quantities of CO_2 emission from firewood and straw burning, respectively, and W (ton) and S (ton) are the consumption quantities of straw and firewood, respectively.

The quantity emission of CO_2 from biogas is

$$\begin{aligned} C_{\mathrm{BG}} = {} & B_{\mathrm{G}} \times 0.209\ ((\text{heat value, TJ}/10 \text{ thousand m}^3) \\ & \times 15.3\ (\text{emission coefficient of carbon, t/TJ}) \\ & \times 44/12 = 11.725 B_{\mathrm{G}}. \end{aligned} \quad (5)$$

In the formula, C_{BG} is quantity of CO_2 emission from biogas, and B_{G} is the consumption quantity of biogas.

3.2. Current situation of CO_2 and SO_2 emission from energy consumption for livelihood in rural China

Besides straw, firewood and coal which are used in rural household for warmth, cooking, heating water and breeding, other fuels, such as LPG, natural gas and coal gas are also used, which merely account for 0.52–1.33% of the total of rural energy consumption. For this reason, the quantity of CO_2 and SO_2 emission from their use is not taken into consideration in the total of energy consumption. Table 3 shows the quantities of CO_2 and SO_2 emission of energy consumption for rural livelihood, calculated according to the method in 3.1.

Between 1996 and 2003, the annual average quantities of CO_2 emissions from straw, firewood and coal consumption calculated in the traditional manner were 373,145.8 thousand tons, 240,541.1 thousand tons and 264,616.4 thousand tons, respectively, accounting for more than 97% of the discharge for rural livelihood, of which straw amounted to 42% of the total. According to the survey, the quantity of SO_2 emission from energy consumption for livelihood over the whole country had decreased from 4970 thousand tons of 1998 to 3673 thousand tons of 2003 [10]. However, because coal

Table 3
The emission quantities of CO_2 and SO_2 of energy consumption for rural livelihood /10^4 t

Year	Emission quantity of CO_2					Total	Emission quantity of SO_2		Total
	Straw	Firewood	Coal	Refined oil	Biogas		Coal	Refined oil	
1996	34,871.72	20,870.82	21,032.56	920.78	186.01	77,881.89	189.53	3.85	193.38
1997	–	–	–	–	208.38	–	–	–	–
1998	33,393.49	25,195.85	23,373.99	1224.21	151.93	83,339.47	210.63	5.12	215.75
1999	36,341.38	19,592.43	22,905.96	1517.49	234.93	80,592.19	206.42	6.35	212.77
2000	35,928.66	20,248.89	24,577.18	1478.95	266.65	82,500.33	221.48	6.19	227.67
2001	38,022.43	24,538.51	28,696.53	2547.84	368.84	94,174.15	258.60	10.67	269.27
2002	41,124.15	28,672.90	32,770.98	1658.27	439.62	104,665.92	295.31	6.94	302.25
2003	41,520.20	29,259.36	31,874.28	1969.27	540.04	105,163.15	287.23	8.24	295.47

Notes: (1) Calculated according to China Rural Energy Statistic [3] and Rural Energy Yearbook [5,6]; (2) Vacant of some datum of 1997.

consumption in the rural areas increased over this period, the discharge of SO_2 did not reduce but increased at a rate of 6.49% from 2157.5 thousand tons in 1998 to 2954.7 thousand tons in 2003, accounting for 43.41% and 80.44% of the total discharge of SO_2, respectively, over the whole country livelihood consumption, respectively. In 2003, the quantities of CO_2 emissions from straw, firewood and coal consumption were 415,202.0 thousand tons, 292,593.6 thousand tons and 318,742.8 thousand tons, respectively, accounting for 39.48%, 27.82% and 30.31%, respectively of the emissions for rural livelihood; while the quantity of SO_2 emission was 2872.3 thousand tons, accounting for 97.21% of the emissions for rural livelihood.

3.3. *Benefit analysis of CO_2 and SO_2 emission reduction by rural household biogas*

With a relatively stable thermal efficiency, biogas is of a high heat value and is also convenient to use, making it next only to LPG for technological economy. According to the situation of biomass energy consumption in the rural area of China and the calculation method in 3.1 and the conversion coefficients of biogas, straw, firewood and coal to standard coal (which are 0.714 kg standard coal/m^3, 0.429 kg standard coal/kg, 0.571 kg standard coal/kg and 0.714 kg standard coal/kg, respectively), if the total output of biogas from 1996 to 2003 was all used to substitute for straw, firewood and coal as energy for livelihood, the annual average quantities of those three fuels that were substituted were 4239.4 thousand ton, 3184.1 thousand ton and 2547.3 thousand ton respectively, accounting for 1.43%,1.93% and 1.43% of their own annual average consumption, respectively (ignoring the loss of heat conversion rate when biogas burning and the loss of thermal efficiency of the methane kitchen range). After the substitution, the annual average quantity of emission reduction of CO_2 was 397.6–4193.9 thousand ton, accounting for 0.048–0.40% of the quantity of CO_2 emission for rural livelihood in the same period. As for SO_2, the numbers were 21.3–62.0 thousand ton and accounting for 1.10–2.10%, respectively. Table 4 shows the quantity of emission reduction by biogas, which substituted traditional energy consumption for livelihood.

Although the structure of rural energy consumption has changed, cooking still plays the leading role in energy consumption in rural households accounting for 40–60% of the total [11]. Generally speaking, biogas-using households use biogas as the fuel for cooking to substitute for traditional-used firewood or coal. From 1996 to 2003, if biogas had been used to substitute for all firewood, the annual discharge of CO_2 could have been reduced by 987.2–2897.8 thousand tons, accounting for 0.13–0.28% of the discharge of CO_2 for rural livelihood in the same period. If all output of biogas was used to substitute for coal, the annual discharge of CO_2 could be reduced by 498.6–1473.9 thousand tons, accounting by 0.06–0.14% of the discharge of CO_2 for rural livelihood, and the annual discharge of SO_2 could be reduced by 34 thousand ton, accounting for 1.39% of the discharge of SO_2 for rural livelihood in the same period. According to the present manner of rural energy consumption in China, if 40% of the output of biogas were used to substitute for firewood and 60% were used to substitute for coal, the annual substituted quantities would be 1273.6 thousand ton and 1528.4 thousand tons, respectively. This would be equivalent to 727.8 and 1091.7 thousand tons of standard coal, which would reduce the annual discharge of CO_2 from cooking by 694.0–2043.4 thousand ton and SO_2 by 12.8–37.2 thousand tons.

Table 4
The quantity of CO_2 and SO_2 emission reduction by biogas, which substituted traditional energy consumption for livelihood from 1996 to 2003 /10^4 t

Years	Biogas		Quantity of emission reduction of CO_2			Quantity of emission reduction of SO_2
	Output (10^4 m^3)	Standard coal	Substituted straw	Substituted firewood	Substituted coal	
1996	158,644	113.30	143.19	98.72	49.86	2.13
1997	177,726	126.95	160.47	110.64	55.90	2.38
1998	129,574	92.08	115.60	79.47	39.76	1.73
1999	200,371	143.07	180.76	124.60	62.91	2.68
2000	227,417	162.29	204.89	141.19	71.21	3.04
2001	314,574	220.00	270.37	184.02	89.16	4.13
2002	374,941	267.69	338.16	233.09	117.66	5.02
2003	460,590	330.21	419.39	289.78	147.39	6.20

Note: (1) Calculated according to China Rural Energy Statistic [3]; (2) 1996–2003, and Rural Energy Yearbook [5,6].

3.4. Forecast of future biogas demand and benefit of CO_2 and SO_2 emission reduction

In the coming decades, straw gasification technology will be further developed; while the direct consumption of biomass energy will continually decrease, and straw will no longer be burnt as a traditional fuel for livelihood. According to the regular scenario of the energy demand forecast of rural China [12], the discharge of CO_2 from rural livelihood will decrease from 1,051,631.5 thousand tons in 2003 to 853,855.8 thousand tons in 2010, to 837,674.8 thousand tons in 2020 and to 769,895.3 thousand tons of 2050. However, the discharge of SO_2 will increase to 5439.5 thousand tons, 1.84 times than that in 2003. In the predicted scheme, the output of biogas will reach 5,950,000 thousand cubic meters, 11,690,000 thousand cubic meters and 35,000,000 thousand cubic meters by 2010, 2020 and 2050, respectively, equivalent to 4250 thousand tons, 8350 thousand tons and 25,000 thousand tons of standard coal. Biogas will be more widely used in rural family life, and the quantity of annual CO_2 emission reduction will be between 1871.3 and 21,787.5 thousand tons from its substitution for biomass energy and coal, accounting for 0.22–2.83% of the discharge of CO_2 for rural livelihood in the same period; while the quantity of annual SO_2 emission reduction will be between 79.7 and 469.0 thousand tons, accounting for 1.94–8.62% of the discharge of SO_2 for rural livelihood in the same period. Table 5 shows the forecast of future biogas demand of the rural area and the emission reduction benefit of biogas's substitution for traditional energy consumption of regular scenario.

Taking the strengthening scenario [12], the quantity of straw consumption for rural livelihood will be zero by 2050, and the quantities of firewood and coal consumption in the form of standard coal will decrease to 14,340 thousand tons and 188,410 thousand tons, respectively. The corresponding discharge of CO_2 will be reduced to 545,168.5 thousand tons, while the discharge of SO_2 will decrease to 3,661.8 thousand tons compared with that in the regular scenario. In this strengthening scenario, the output of biogas in 2010 and 2050 will reach 9,786,000 thousand cubic meters and 73,780,000 thousand cubic meters,

Table 5
Forecast of future biogas demand of the rural area and the emission reduction benefit of biogas substitution for traditional energy consumption of regular scenario 10^4 t

Years	Biogas		Discharge of CO_2 emission reduction		Discharge of SO_2 emission reduction
	Output (10^4 m^3)	Standard coal	Substituted firewood	Substituted coal	
2010	595,000	425	370.39	187.13	7.97
2020	1,169,000	835	727.71	367.65	15.66
2050	3,500,000	2500	2178.75	1100.75	46.90

Note: Calculated according to the datum of the information [12].

Table 6
Enhanced forecast of future demand of biogas of rural area and the benefit of emission reduction from biogas' substitution for traditional energy consumption /10^4 t

Years	Biogas		Discharge of CO_2 emission reduction		Discharge of SO_2 emission reduction
	Output (10^4 m^3)	Standard coal	Substituted firewood	Substituted coal	
2010	978,600	699	609.18	307.77	13.11
2020	3,039,400	2171	1892.02	955.89	40.73
2050	7,378,000	5270	4592.80	2320.38	98.87

Note: Calculated according to the datum of the information [12].

respectively, equivalent to 6990 and 52,700 thousand tons of standard coal [12]. The substitution of biogas for firewood and coal will reduce the annual discharges of CO_2 and SO_2 during these 40 years by 3077.7–45,928.0 thousand tons and 131.1–988.7 thousand tons, respectively, accounting for 0.39–8.42% and 3.6–27% of the total discharges of CO_2 and SO_2 in rural livelihood at that time. Table 6 shows the strengthening scenario of future demand of biogas in rural areas and the benefit of emission reduction resulting from biogas' substitution for traditional energy consumption.

4. Conclusions

Over 80% of China's population lives in the rural areas and their energy consumption is far lower than that in the cities. Traditional biomass energy accounts for more than 60% of the energy consumed for rural livelihood. The burning of these energy sources produced such noxious gases as CO_2, SO_2 and other harmful products, which threaten human health and environmental security. Straw, firewood and coal are important energy sources for rural daily life, but the discharge of CO_2 caused by them accounts for more than 97% of the annual total livelihood discharge in rural livelihood. Between 1996 and 2003, the annual average output of rural household biogas in China was 2,554,796.95 thousand cubic meters, equivalent to 1824.1 thousand tons of standard coal. The output of biogas

every year completely substituted for straw, firewood and coal as the energy for rural family's daily life, which led the annual average quantity of CO_2 emission reduction to be 397.6–4193.9 thousand ton and that of SO_2 emission reduction to be 17.3–62.0 thousand ton. It is estimated that the future construction of biogas projects in the rural areas of China will bring great benefit to rural ecological environment by reduction of harmful gas emissions. According to the enhanced forecast scheme of energy for rural livelihood, between 2010 and 2050, the substitution for biomass energy and coal by biogas can reduce the annual discharge of CO_2 by 3077.7–45,928.0 thousand tons and that of SO_2 by 131.1–988.7 thousand tons.

Biogas construction in the rural areas will not only effectively advance the development of renewable energy in China, but also alleviate the pressure of the rural energy demand and make a significant contribution to the reduction of CO_2 and SO_2 emission. Biogas construction effectively utilizes the waste from rural life and production, and has improved the living environment of rural residents. Therefore, the construction of rural household biogas project should be further developed by continuing technological improvements in the formed biogas pools, and improving the efficiency of biogas production. This will help rural households to become active in building the biogas pools by offering them economic and technical support. Thus, the rural ecological environment will be greatly improved.

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